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Aviation Medical Acceleration Laboratory

NADC-ML-6408 26 June 1964

Effect of Oxygen Enriched Atmospheres on the Burning Rate of Fabrics - Phase II

Bureau of Naval Weapons
Weptask RAE 20J 010/2021/F012 10 02
Problem Assignment 010-AE13-13

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Prepard by: Maria A. Chianta

Maria A. Chianta

Alice M. Stoll

Alice M. Stoll

Approved and Released by: Carl F. Schmidt

Carl F. Schmidt, M.D.
Research Director
Aviation Medical Acceleration Laboratory

SUMMARY AND CONCLUSIONS

This study, designed to ascertain the feasibility of oxygen enrichment of capsular environments without increasing clothing fire hazard, has: 1) revealed that under the conditions of these experiments, with the best fire-resistant clothing material available, only a 10% increase in oxygen concentration may be realized in an oxygen-nitrogen atmosphere irrespective of pressure; similarly, a 20% increase, if argon is used; 2) demonstrated the existence and progression of the damping effect of inert gases; and 3) suggested a means of extending observations made in one gaseous environment to any other of known physical properties.

It is concluded that significant oxygen enrichment may be achieved safely only by introduction of a physiologically safe gas or gas mixtures at least twice as dense as nitrogen.

ACKNOWLEDGMENT

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INTRODUCTION

Observations of enhancement in burning rates of fabrics and the unquenchability of fires in capsular environments of 100% oxygen (1, 2) prompted the present investigation. At the time of these observations this oxygen concentration at a pressure of 4.6 psia (equivalent to 29, 000 feet) was the cabin atmosphere generally favored (3). Therefore, the initial experiments were undertaken to determine whether oxygen enrichment could be maintained at some concentration less than 100% but significantly more than atmospheric without increasing the fire hazard presented by the ignition of clothing. Subsequently the study was broadened to include a range of pressures and a diluent other than nitrogen.

MATERIAL AND METHOD

The clothing material examined was representative of the lightest material anticipated for wear within a space capsule on an extended mission, i.e., 5 oz/yd^2 cotton used in Navy issue pajamas. As a control 2.5 oz/yd^2 cotton sheeting was used, and as the best fire resistant, untreated clothing material currently available 3.0 oz/yd^2 HT-1* (4) twill also was studied.

The apparatus consisted of an altitude chamber provided with a nichrome heater for igniting the fabrics and an iron-constantan thermocouple for assessing heater output and ignition temperatures. The nichrome element ensured a reproducible and constant heat supply at any pressure that might be encountered throughout the range of altitude from sea level to 29, 000 feet. The element was made of 30 turns of 25 gauge wire wound on a 3/16 inch form. Voltage was supplied through a Variac autotransformer at the 20 volt tap and drew a current of 9 amps. The salient features of the apparatus are shown schematically in Figure 1. It provided for evacuation of the chamber to 0.40 psia (equivalent to 80, 000 feet altitude or 20.9 mm Hg). The oxygen supply could be maintained at a constant flow and pressure by means of the gauge valves. The circuitry provided a master switch for turning on the element and the two timers simultaneously and also provided for turning off one of the timers independently of the master switch. The iron-constantan thermocouple was placed approximately 1/16 inch from the apex of the heating element and the output fed into a recording oscillograph.

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* E.I. Du Pont de Nemours polyamide textile fiber now marketed as "Nomex".

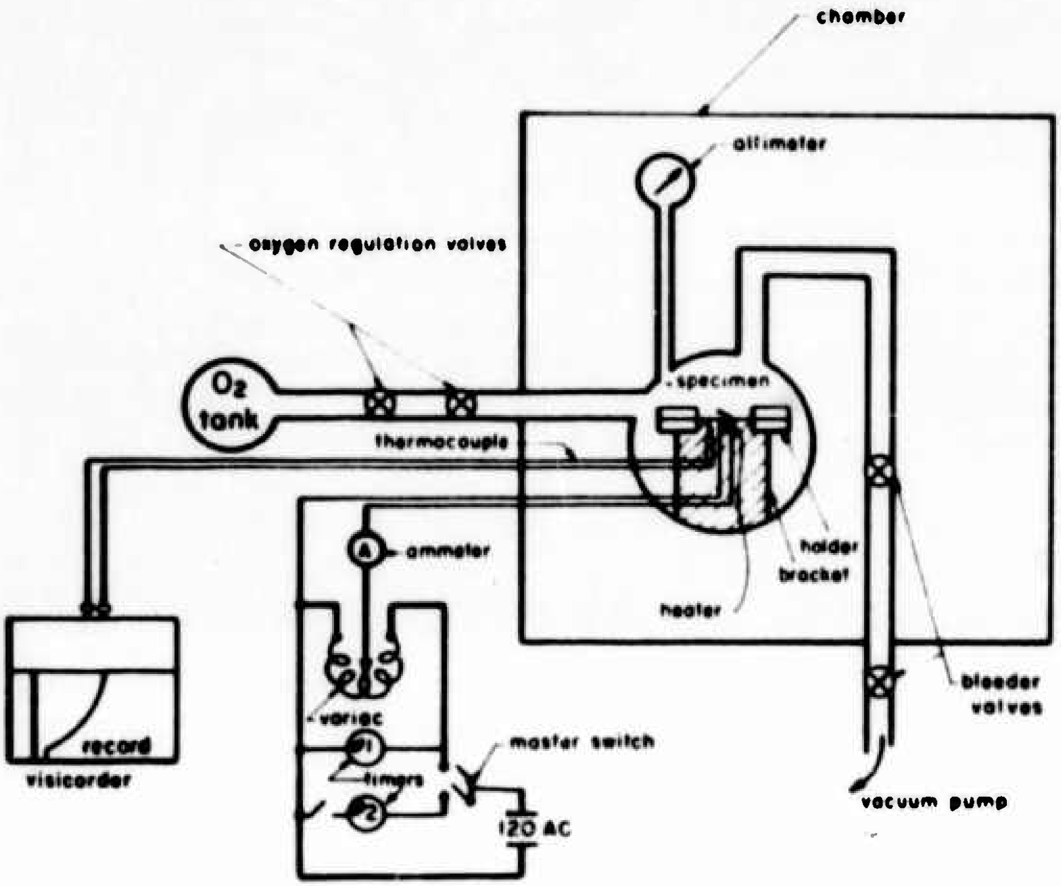

Figure 1. Schematic of Exposure Chamber.

For ignition studies, the fabrics were prepared in squares, 9.5 cms on edge. Each specimen was mounted between two asbestos plate rings so that a circular area, 6.5 cms in diameter, was exposed to the heat from the element which was situated 2 mms beneath the fabric.

The gas mixtures used in the first part of this study were combinations of oxygen and nitrogen graded in compositon from 20 to 100% oxygen in increments of 10%. The pressures used were 4.6, 7.4, 10.9, and 14.7 psia, equivalent to altitudes of 29,000, 18,000, 8,000 and zero feet, respectively. The experimental procedure followed in preparing for each run was to set the fabric sample in place above the heater and seal the chamber airtight; evacuate the chamber to 0.4 psia; return the chamber to one atmosphere with the gas mixture; evacuate the chamber again to the pressure level desired, maintain that pressure by equalizing the inflow and outflow, and wash the fabric for 5 minutes with a continuous flow of the gas mixture. This flow, then, was continuous throughout the burning of the specimen and no attempt was made to compensate for the increase in pressure due to gaseous products formed during the burning of some fabrics, but at no time was this increase greater than 0.3 psia. When the desired atmospheric conditions had been established, the fabric was ignited and the entire burning sequence was observed through a glass porthole in the door. This part of the procedure required starting the thermocouple output recorder and then throwing the master switch. The latter actuated the timers and the power supply to the heating element.

Three points in the subsequent heating and burning episode were observed and marked on the record: the "scorch" point, i.e., the time of the first sign of scorching; "flame" point, i.e., the time at which flaming occurred; "flameout", i.e., the time at which the flame extinguished, often due to complete consumption of the specimen.

RESULTS AND DISCUSSION

The plot of the results obtained with the 5 oz/yd^2 cotton material at 29,000 feet as shown in Figure 2 serves to illustrate the burning pattern observed generally with all three materials at the four pressures studied. It should be emphasized at this point that the data obtained in these experiments provide relative rather than absolute information and depend strongly upon the heating technique used. Thus, if greater or lesser heat were supplied the ignition times, and consequently total destruction rates, would of course vary directly. It is seen that the scorch point varies relatively little with oxygen concentration but that the flaming point and total destruction is reached far more rapidly as oxygen content increases. All progressions are smooth and no optima or discontinuities are evident. From

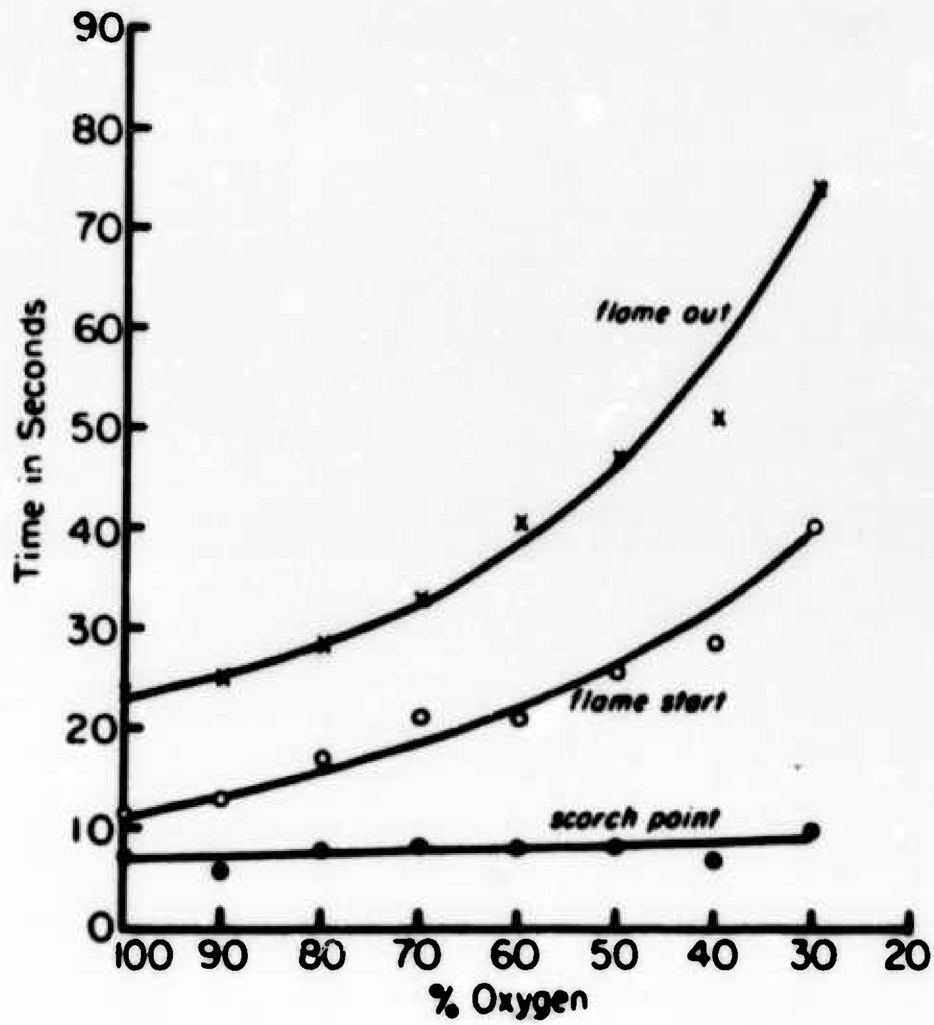

Figure 2. Burning Pattern of 5 oz/yd^2 Cotton Fabric.

these data it appears that no optimal combination of O_2 and N_2 exists. However, the data obtained under these experimental conditions show that the properties of the material itself may offer significant advantages. These data are presented in Table I in terms of destruction rates calculated from the observed total burning time normalized by correcting for the differences in weight of the fabrics. It is seen that at each altitude the 5 oz/yd^2 cotton was destroyed most rapidly, the 2.5 oz/yd^2 cotton less rapidly, and the HT-1 material least rapidly. This advantage is also illustrated in Figure 3 where the data taken at 4.6 psia (29,000 ft.) are shown graphically. It is seen that in the instances of HT-1, thermal destruction not only started later, but also proceeded more slowly, while the material did not flame at all in the 30% O_2 environment. Furthermore, it was observed that at 40% O_2 the flame extinguished itself as soon as the material in the immediate vicinity of the heater was destroyed. On the other hand, at high oxygen concentrations this material burst into flames suddenly and burned fiercely when once ignited. The temperatures associated with these events were also higher than comparable temperatures of the cottons at oxygen levels above 50% as seen in Figure 4. All flame point temperatures were between 625 and 725°C, however, and differences within this stratum must be considered to be insignificant in view of the height of the temperature level itself. In the absence of flaming, destruction of the HT-1 occurred through charring and at a much lower temperature. These data suggested that flaming is dependent upon both a sufficiency of oxygen and an insufficiency of damping effect of nitrogen in the mixtures of higher oxygen concentration. Since the cottons flame even at the lowest concentration of oxygen used, this damping effect is obscured. However, from the observed prolongation of time to flaming as the oxygen concentration decreases (Figure 2), it may be inferred to occur to some extent with the cottons also.

The destruction rates of HT-1 at all gas concentrations and levels of pressure studied are shown in Figure 5 plotted on triangular coordinates to reveal the decrease in rate with an increase in altitude and a decrease in oxygen concentration in agreement with early observations of a similar nature (5). In order to examine the hypothesis of a damping effect, the concentration of gases pertaining to these exposures were converted from the partial pressures and volume percentages to weights, corrected to 25°C ambient temperature, and arranged as shown in Figure 6. Here the weights of gases present are related to each other as well as to the equivalent altitudes and per cent concentrations. The observation of the occurrence or non-occurrence of flaming was made in three exposures under the conditions represented by each plotted point. It can be seen that flaming occurred at all points within the zone above the line corresponding to 30% O_2 - 70% N_2, and no flaming occurred at any point below the line despite the fact that the

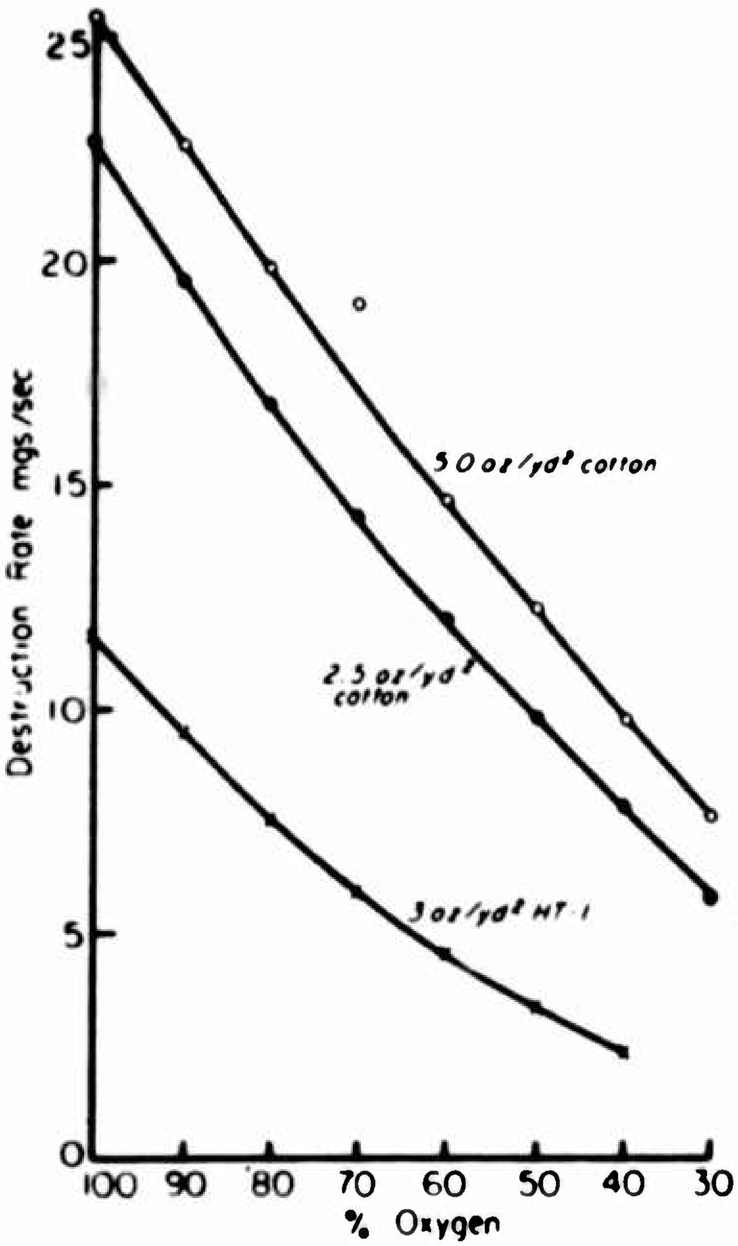

Figure 3. Fabric Destruction Rate.

TABLE I

DESTRUCTION RATE IN O_2/N_2 ENVIRONMENTS

(mgs/sec)

% O_2	Pressure 4.58 (psia) Altitude 29,000 ft			Pressure 7.35 (psia) Altitude 18,000 ft.			Pressure 10.92 (psia) Altitude 8,000 ft.			Pressure 14.7 (psia) Altitude 0 ft.		
	5 oz/yd^2 cotton	2.5 oz/yd^2 cotton	3 oz/yd^2 HT-1	5 oz/yd^2 cotton	2.5 oz/yd^2 cotton	3 oz/yd^2 HT-1	5 oz/yd^2 cotton	2.5 oz/yd^2 cotton	3 oz/yd^2 HT-1	5 oz/yd^2 cotton	2.5 oz/yd^2 cotton	3 oz/yd^2 HT-1
100	25.4	22.6	11.6	30.5	21.2	14.2	35.6	22.9	19.3	33.9	21.2	14.2
90	22.5	19.5	9.5	28.8	18.7	13.2	32.2	19.5	14.2	39.0	19.5	14.2
80	19.8	16.8	7.6	28.8	17.0	10.2	30.5	18.7	14.2	33.0	18.7	12.2
70	19.0	14.3	6.0	23.7	16.1	9.2	27.1	17.8	11.2	30.5	16.1	11.2
60	14.6	12.0	4.6	23.7	14.4	6.2	27.1	16.1	10.2	32.2	19.5	10.2
50	12.2	9.8	3.4	20.3	14.4	3.1	23.7	15.3	5.7	25.4	16.1	7.1
40	9.8	7.8	2.4	15.3	12.7		22.0	15.3	4.1	22.0	15.3	6.0
30	7.6	5.8					13.9	12.7		18.6	13.6	3.5

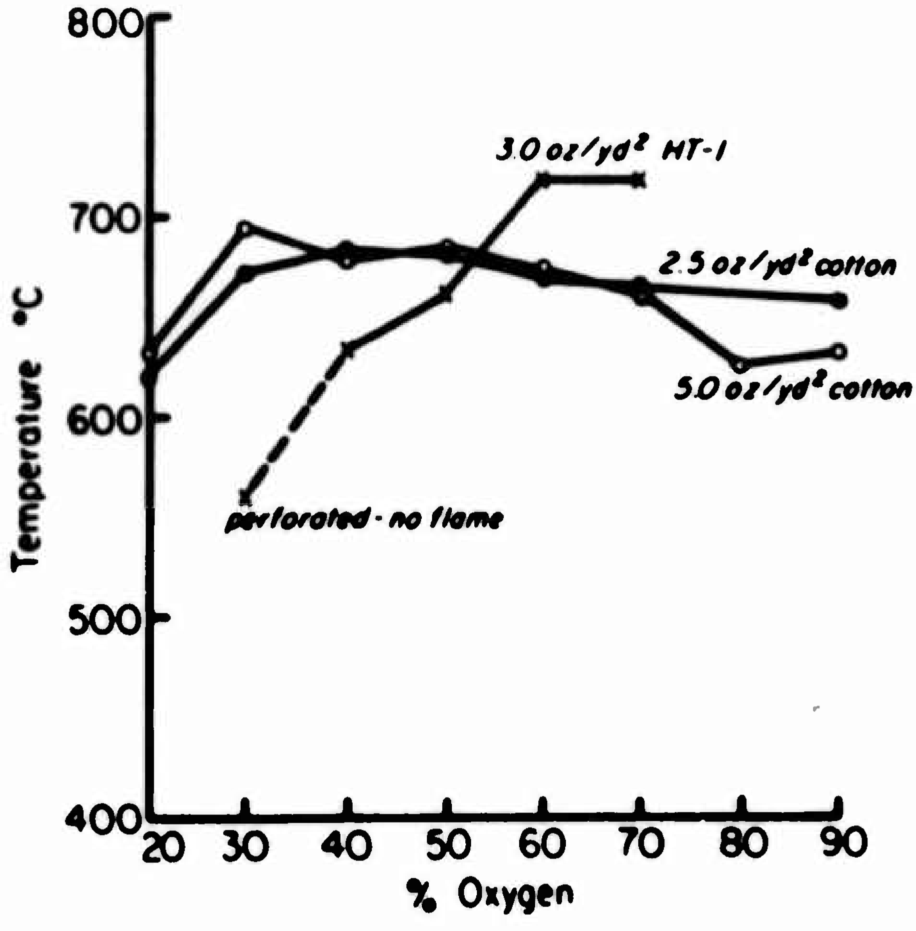

Figure 4. Flame Point Temperature.

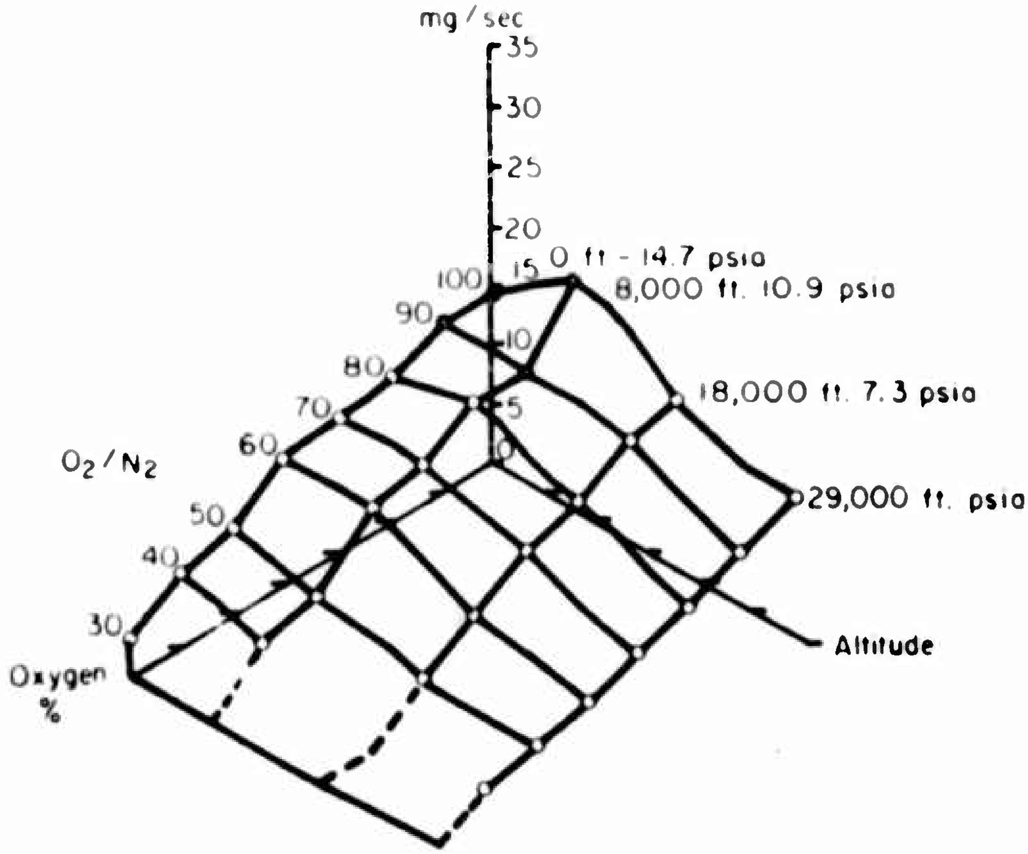

Figure 5. Destruction Rate Profile, HT-1.

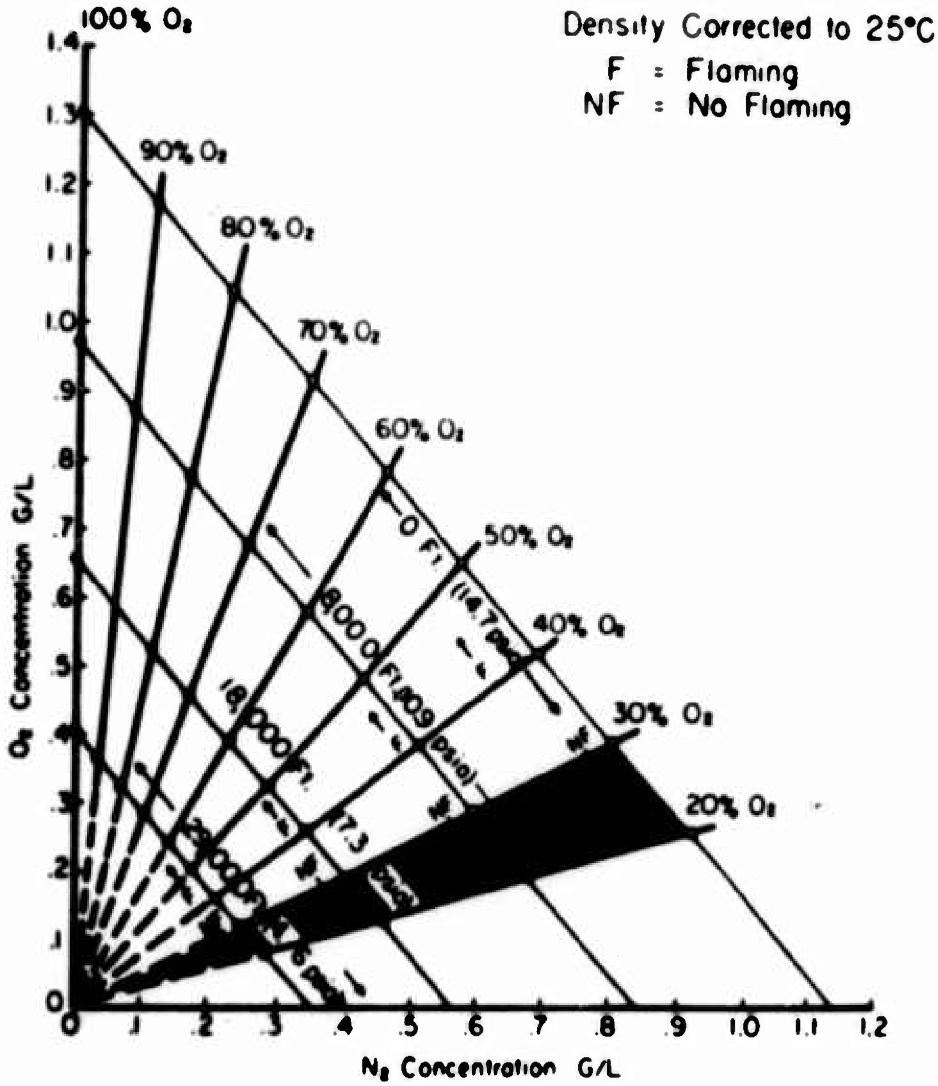

Figure 6. Combustion of Fire-Resistant Fabric in Oxygen/ Nitrogen Atmospheres.

absolute amount of oxygen present was sufficient to permit and support combustion. The latter point is clearly demonstrated by the fact that flaming occurred at a concentration of 0.163 g/l (40% O_2 - 29,000 ft.) but not at a concentration of 0.196 g/l (30% O_2 - 18,000 ft.) or even 0.392 g/l (30% O_2 - 0 ft.). There can be no doubt that the damping effect is real. It would appear then that a heavier gas would be even more effective. To test this hypothesis a series of exposures were made with oxygen-argon mixtures. Theoretically, from the oxygen-nitrogen data, as shown, Figure 6, a minimum of 0.163 g/l of oxygen is required for combustion while the maximum ratio lies between 48 and 75% of O_2/N_2 by weight corresponding to 30% and 40% O_2 respectively. These criteria are met at the 40% O_2-60% A level where the ratio of oxygen to argon by weight is 53%. Experiment revealed that flaming did not occur in this environment at any point except at the pressure equivalent to 8,000 feet. At this point flaming did occur after an extended exposure of 920 seconds whereas under comparable conditions in the oxygen-nitrogen mixture flaming occurred at 43 seconds. For some as yet unknown reason, in all fabrics, destruction proceeds in some instances more rapidly at this pressure than at any other studied, as seen in Table II. This phenomenon occurred irrespective of the diluent gas used. Therefore, the fact that flaming occurred only at this most vulnerable point in the series of four pressure levels was taken as an indication that the ratio of 53% O_2 to inert gas is the borderline concentration required for flaming. Extending this concept to a heavier gas, e.g., krypton, no flaming should occur at the 60% O_2 - 40% Kr level where the ratio by weight is 39% but should occur at the 70% O_2 - 30% Kr level where the ratio is 60%. This experiment is scheduled but at the time of this report has not yet been done. Assuming, however, that the theory is borne out by experimental evidence, enriching the atmosphere without increasing fire hazard becomes a physical possibility although perhaps not a physiological one due to the noxious character of heavy gases such as krypton and xenon (6). In any event, it precludes the necessity for further experimentation with gas mixtures and permits calculation of the effects of given concentrations of any inert gas of known density on the combustion of material from data establishing its burning characteristics in any known oxygen-inert gas mixture.

TABLE II

DESTRUCTION RATE IN O_2/N_2 ENVIRONMENTS
(mgs/sec)

% O_2	5 oz/yd² cotton Pressure (psia) and Altitude (ft.)				2.5 oz/yd² cotton Pressure (psia) and Altitude (ft.)				3 oz/yd² HT-1 Pressure (psia) and Altitude (ft.)			
	4.50 29,000 ft.	7.35 18,000 ft.	10.92 8,000 ft.	14.7 0 ft.	4.50 29,000 ft.	7.35 18,000 ft.	10.92 8,000 ft.	14.7 0 ft.	4.50 29,000 ft.	7.35 18,000 ft.	10.92 8,000 ft.	14.7 0 ft.
100	25.4	30.5	35.6	33.9	22.6	21.2	22.9	21.2	11.6	14.3	19.3	14.2
90	22.5	28.8	32.2	39.0	19.5	18.7	19.5	19.5	9.5	13.2	14.2	14.2
80	19.8	28.8	30.5	33.9	16.8	17.0	18.7	18.7	7.6	10.2	14.2	12.2
70	19.0	23.7	27.1	30.5	14.3	16.1	17.8	16.1	6.0	9.2	11.2	11.2
60	16.6	23.7	27.1	32.2	12.0	14.4	16.1	19.5	4.6	6.2	10.2	10.2
50	12.2	20.3	23.7	25.4	9.8	14.4	15.3	16.1	3.4	3.1	5.7	7.1
40	9.0	15.3	22.0	22.0	7.8	12.7	15.3	15.3	2.4		4.1	6.0
30	7.6		13.9	20.6	6.8		12.7	13.6				3.5

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